10B.4 The Effect of the Saharan Air Layer on the Formation of Hurricane Isabel (2003) Simulated with AIRS Data

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1. Introduction

The crucial physics of how the atmosphere really accomplishes the tropical cyclogenesis process is still poorly understood. The presence of the Saharan Air Layer (SAL), an elevated mixed layer of warm and dry air that extends from Africa to the tropical Atlantic and contains a substantial amount of mineral dust, adds more complexity to the tropical cyclogenesis process in the Atlantic basin. The impact of the SAL on tropical cyclogenesis is still uncertain. Karyampudi and Carlson (1988) conclude that a strong SAL can potentially aid tropical cyclone development while Dunion and Velden (2004) argue that the SAL generally inhibits tropical cyclogenesis and intensification. Advancing our understanding of the physical mechanisms of tropical cyclogenesis and the associated roles of the SAL strongly depends on the improvement in the observations over the data-sparse ocean areas.

After the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), and the microwave Humidity Sounder of Brazil (HSB) were launched with the NASA Aqua satellite in 2002, new data products retrieved from the AIRS suite became available for studying the effect of the warm, dry air mass associated with the SAL (referred to as the thermodynamic effect). The vertical profiles of the AIRS retrieved temperature and humidity provide an unprecedented opportunity to examine the thermodynamic effect of the SAL. The observational data can be analyzed and assimilated into numerical models, in which the model thermodynamic state is allowed to relax to the observed state from AIRS data. The objective of this study is to numerically demonstrate that the thermodynamic effect of the SAL on the formation of Hurricane Isabel (2003) can be largely simulated through nudging of the AIRS data.

2. Simulation description

Hurricane Isabel originated from a tropical wave near the western coast of Africa on 1 September. A tropical depression centered at 13.8°N, 31.4°W formed at 0000 UTC 6 September. It became Tropical Storm Isabel six hours later and intensified into a hurricane at 1200 UTC 7 September. To understand the SAL influence on the formation of Isabel, numerical simulations are conducted from 1 to 12 September 2001 using MM5. The integration period includes the formation and intensification of Isabel (it reached its peak intensity of 145 knots on 11 September) and the evolution of a tropical disturbance to the east. A single domain is used consisting of 226×481grid points with a 21-km spacing covering an area from 1.7°S to 37.5°N and 89.5°W to 0.9°E. There are 28 vertical levels with higher resolution in the planetary boundary layer (PBL).

In the control experiment, the thermodynamic effect of the SAL is assimilated through the nudging technique, which forces the model state to be relaxed toward the observations by adding a Newtonian relaxation term in a prognostic equation (Stauffer and Seaman 1990). The nudging of AIRS data is conducted continually through the integration period for the whole domain including both daytime and nighttime data. For comparison, a second experiment is conducted using the same model setup but without the observational nudging.

3. Results

Although the SAL effect is to some extent represented in the initial and lateral boundary conditions in the case without nudging of AIRS data, the subsequent evolution of the SAL effect actually is poorly represented due to a lack of the relevant model physics (Fig. 1). One reason is that the presence of the SAL mineral dust can affect the thermodynamic state through radiative heating (Carlson and Benjamin 1980) and likely through modifying cloud processes by serving as cloud condensation nuclei (CCN) or ice nuclei (van den Heever 2005). These effects are considered indirectly through the corrections of the nudging technique. As shown in Fig. 1, the nudging of the AIRS data can better simulate the relative humidity pattern.

In the nudging experiment, a latitude-height cross section of the zonal wind averaged over 15 – 40 °W (Fig. 2) indicates that the SAL is associated with an easterly wind maximum of about 10 m s^{-1} around 18°N at a height of 4 km and an upper-level westerly maximum at about 12 km. These features are consistent with those in the NCEP reanalysis, suggesting that nudging of AIRS data can effectively simulate the thermodynamic effect of the SAL. As a result, the mean wind shear between 4 km and 10 km increases from 1 ms^{-1} in the non-nudging experiment to 3 m s^{-1} in the control experiment due to the enhanced mid-level easterly maximum. There is only a small increase in the vertical shear below 4 km. In agreement with Dunion and Velden (2004), the presence of the SAL suppresses Atlantic

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tropical cyclone activity by increasing the local vertical wind shear via enhanced mid-level winds. Wu et al. (2006) also suggest that the SAL can reduce the relative humidity and stabilizing the environment at lower levels.

In the nudging experiment, the timing and location of formation and the subsequent track of Hurricane Isabel are well simulated (Wu et al. 2006). The simulated tropical cyclone formed at 0600 UTC September 5, one day earlier than observed. The formation location is at 13.5°N, 30.9°W, which is comparable to the observed at 13.9°N, 32.7°W. The simulated tropical cyclone moves slightly slower than the observed storm. Based upon the maximum wind at the lowest model level (38 m), the simulated tropical cyclone reaches hurricane strength at 1800 UTC September 6, also one day earlier than the observed. In the experiment without nudging of the AIRS data, on the other hand, the simulated tropical cyclone evolution is dramatically different than the observations. The simulated tropical disturbance associated with Isabel becomes a tropical storm at 1200 UTC September 2, four days earlier than observed. The simulated storm takes a track different from Isabel by moving to its north. An additional tropical cyclone forms just off the western coast of Africa. These two experiments clearly demonstrate that the effect of the SAL may have delayed the formation of Hurricane Isabel and inhibited the development of the other tropical disturbance to the east. The simulation results also suggest that the nudging technique effectively incorporates the SAL effect in the simulation.

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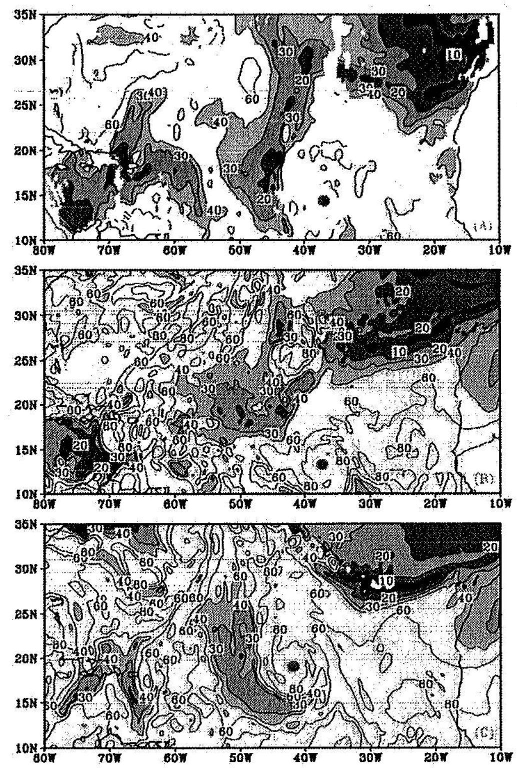

Figure 1 The 700 hPa relative humidity field on 7 Sept. 2003, for AIRS (upper), nudging (middle), and non-nudging (lower) simulations. The shading areas indicate the relative humidity is drier than 30%. The closed dots indicate the observed and simulated tropical cyclone locations.

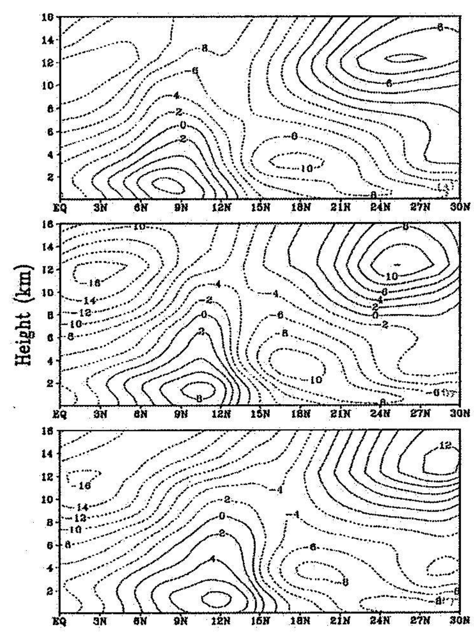

Figure 2 Latitude-height cross-section of zonal winds averaged over 15-40°W from 1-12 Sept. 2003, for NCEP reanalysis (upper), nudging (middle) and non-nudging (lower) experiments.